

Medium-Term Risk Management for a Gas-Fired Power Plant

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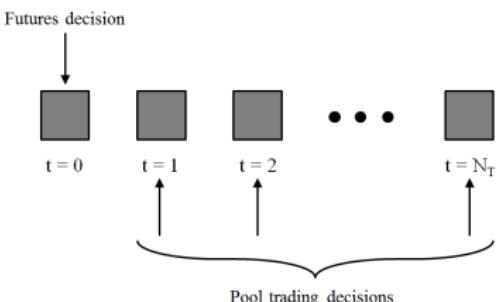
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Introduction

Motivation

- Deregulation of the electricity industry is meant to improve efficiency by providing market signals to decision makers
 - Wilson (2002) outlines the contours of these reforms
 - Producers now need to control risk (Deng and Oren, 2006)
 - Risk management is particularly important for UK power producers because of the “dash for gas” (DUKES, 2012)
 - Stochastic programming provides one such framework
 - Representation of uncertainty with multi-stage decisions
 - Incorporate technical constraints
 - Handle risk directly



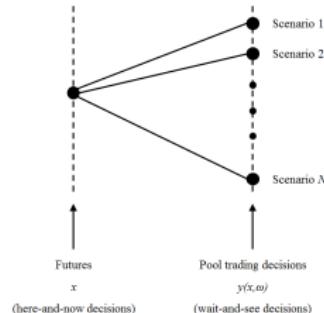
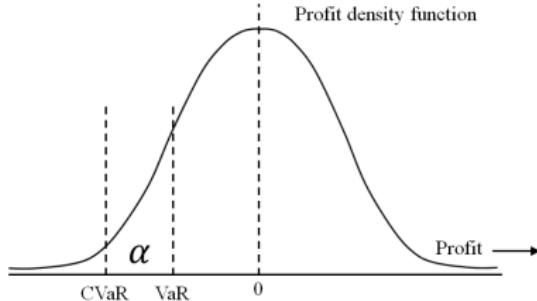
Research Objective and Related Work

- Oum and Oren (2008) provide an analytical treatment of an electricity retailer's VaR-constrained problem
 - Most problems need to be addressed numerically via scenarios
 - Contreras et al. (2003) and Conejo et al. (2005) use ARIMA models to generate scenarios for Spanish electricity markets
 - Rockafellar and Uryasev (2002) incorporate CVaR constraints
 - Conejo et al. (2010) apply this framework to various problems in the power sector
 - Our contribution is as follows:
 - A UK-based case study outlining the risk-return tradeoff
 - Incorporation of uncertainty in the fuel price
 - Insights about the effects of technological constraints on hedging decisions

Problem Formulation

Assumptions

- Two-stage problem for a profit-maximising producer: monthly futures contract with daily pool trading and generation decisions
- Futures trading may affect futures prices, but pool prices are exogenous
- Uncertainty is represented via discrete scenarios resulting from time-series analysis
- CVaR is the coherent risk measure used



Objective Function

$$\begin{aligned} & \max_{P_{f,j}^F, Q_{g,h,i}^F, E_{t,\omega}^P \geq 0, E_{g,t,\omega}^G, \xi, \eta_\omega \geq 0} \\ & \sum_{\omega=1}^{N_\Omega} \pi_\omega \sum_{t=1}^{N_T} \left(\sum_{f \in F_t} \sum_{j=1}^{N_J} \lambda_{f,j}^F P_{f,j}^F d_t + \lambda_{t,\omega}^P E_{t,\omega}^P - \sum_{g=1}^{N_G} \left(\sum_{h \in H_t} \sum_{i=1}^{N_I} \mu_{h,i}^F Q_{g,h,i}^F \right. \right. \\ & \left. \left. + \mu_{t,\omega}^P \left(\frac{E_{g,t,\omega}^G}{e_g} - \sum_{h \in H_t} \sum_{i=1}^{N_I} Q_{g,h,i}^F \right) \right) \right) + \beta \left(\xi - \frac{1}{1-\alpha} \sum_{\omega=1}^{N_\Omega} \pi_\omega \eta_\omega \right) \end{aligned} \quad (1)$$

Constraints

$$0 \leq P_{f,j}^F \leq \bar{P}_{f,j}^F, \quad \forall f, j = 1, \dots, N_J \quad (2)$$

$$0 \leq \sum_{g=1}^{N_G} Q_{g,h,i}^F \leq \bar{Q}_{h,i}^F, \quad \forall h, i = 1, \dots, N_I \quad (3)$$

$$0 \leq E_{g,t,\omega}^G \leq P_q^{G,max} d_t, \quad \forall g, \forall t, \forall \omega \quad (4)$$

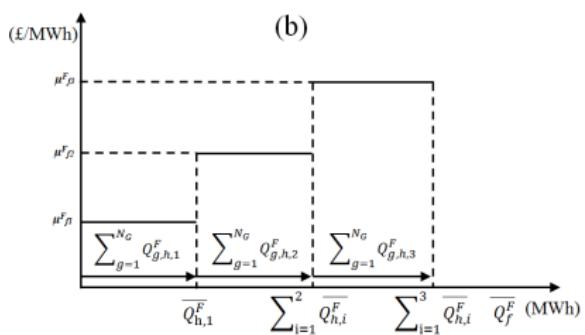
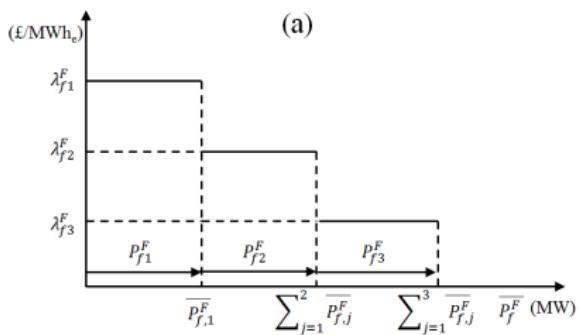
$$E_{g,t,\omega}^G \geq L_g E_{g,t',\omega}^G \quad , \quad \forall g, \forall \omega, \forall t, t' | W(t, t') = 1 \quad (5)$$

$$\sum_{g=1}^{N_G} E_{g,t,\omega}^G = E_{t,\omega}^P + \sum_{f \in F_t} \sum_{j=1}^{N_J} P_{f,j}^F dt, \quad \forall t, \forall \omega \quad (6)$$

$$\xi - \sum_{t=1}^{N_T} \left(\sum_{f \in F_t} \sum_{j=1}^{N_f} \lambda_{f,j}^F P_{f,j}^F d_t + \lambda_{t,\omega}^P E_{t,\omega}^P - \sum_{g=1}^{N_G} \left(\sum_{h \in H_t} \sum_{i=1}^{N_h} \mu_{h,i}^F Q_{g,h,i}^F \right. \right. \\ \left. \left. + \mu_{t,\omega}^P \left(\frac{E_{g,t,\omega}^G}{e_g} - \sum_{h \in H_t} \sum_{i=1}^{N_h} Q_{g,h,i}^F \right) \right) \right) \leq \eta_\omega, \quad \forall \omega \quad (7)$$

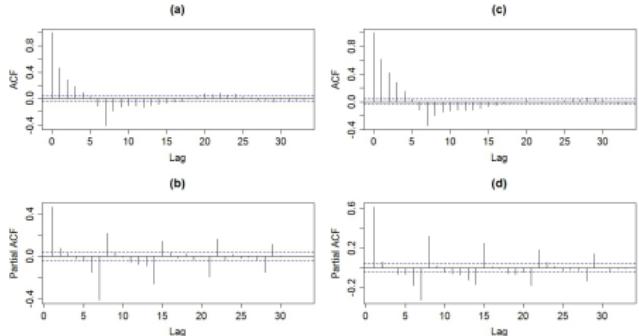
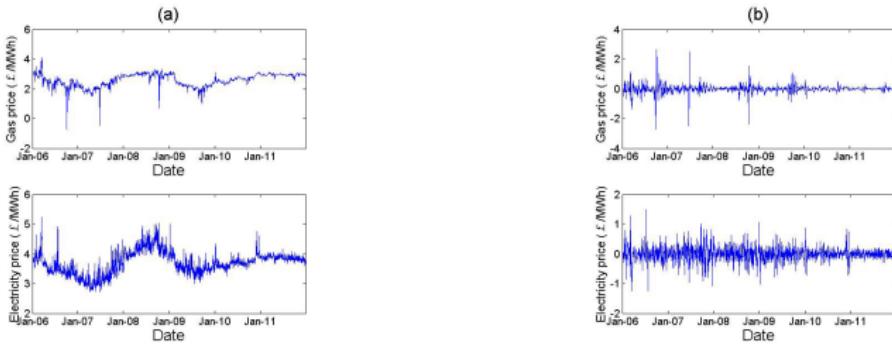
$$\frac{E_{g,t,\omega}^G}{e_g} - \sum_{h \in H_t} \sum_{i=1}^{N_I} Q_{g,h,i}^F \geq 0, \quad \forall g, \forall t, \forall \omega \quad (8)$$

Futures Contracting



Representation of Uncertainty

UK Energy Prices



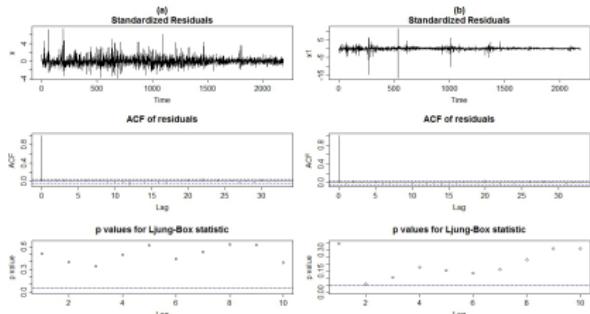
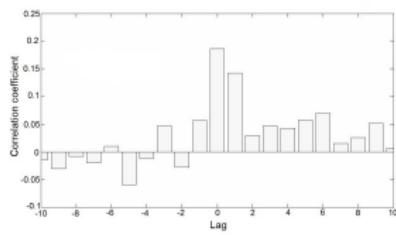
Time-Series Analysis

- We use the following ARIMA model for the energy prices:

$$(1 - \phi_1 B - \phi_2 B^2)(1 - B^7) \log(y_t) \\ = (1 - \theta_1 B - \theta_7 B^7 - \theta_8 B^8)\epsilon_t \quad (9)$$

- However, electricity and gas prices are non contemporaneous
 - Thus, the following transfer function is used:

$$\log(y_t) = (w_0 + w_1 B) \log(x_t) + \frac{1 + \phi_1 B + \phi_2 B^2}{1 - \theta_1 B - \theta_7 B^7 - \theta_8 B^8} \epsilon_t \quad (10)$$



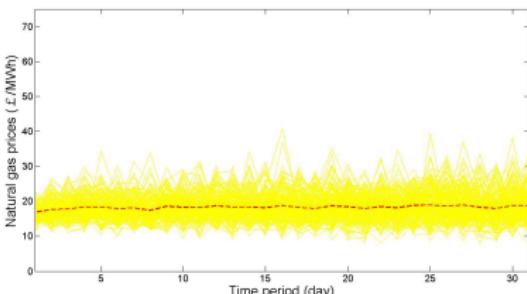
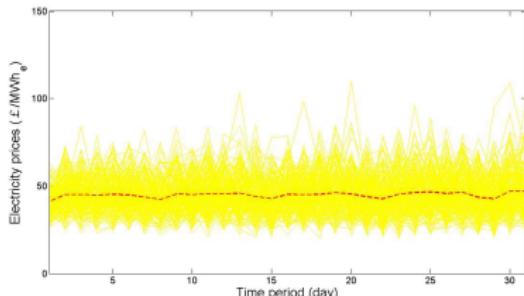
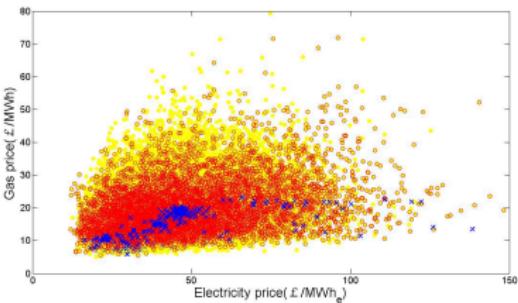
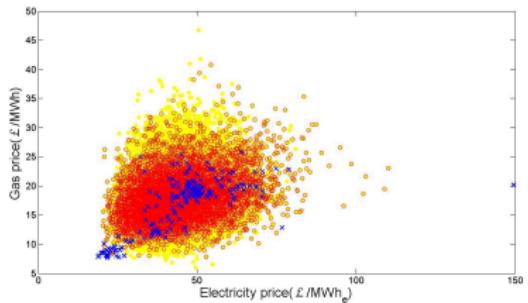
Scenario Generation and Reduction

- Scenario generation using error term from time series:
 - ① Initialise the scenario counter $\omega = 0$
 - ② Update the scenario counter $\omega = \omega + 1$ and initialise the time-series counter $t = 0$
 - ③ Update the time-series counter $t = t + 1$
 - ④ Generate $\epsilon \sim \mathcal{N}(0, \sigma^2)$ randomly
 - ⑤ Evaluate the general form of (9) to obtain $y_{t\omega}$
 - ⑥ Go to 3) if $t \leq N_T$; else go to 7)
 - ⑦ Go to 2) if $\omega \leq N_\Omega$; else the procedure concludes
- Scenario reduction uses Kantorovich distance

$$D_K(\mathcal{Q}, \mathcal{Q}') = \sum_{\omega \in \Omega \setminus \Omega_S} \pi_\omega \min_{\omega' \in \Omega_S} v(\omega, \omega'), \text{ where}$$

$$v(\omega, \omega') = \|\lambda(\omega) - \lambda(\omega')\| \quad (\text{Dupačová et al., 2003})$$

Output



Numerical Examples

Cases and Technology Parameters

- Case 1: deterministic generation cost
 $C_g^G = \frac{1}{N_T \times N_\Omega \times e_g} \sum_{\omega=1}^{N_\Omega} \sum_{t=1}^{N_T} \mu_{t,\omega}^P$ and only electricity futures
- Case 2: stochastic NG pool price and only electricity futures
- Case 3: stochastic NG pool price and both electricity/NG futures
- Technology parameters:
 - $P_g^{G,max} = 500 \text{ MW}_e, L_g = 0.33, N_T = 31, N_\Omega = 200,$
 $C_g^G = £40.62/\text{MWh}_e, e_g = 0.45, \alpha = 0.95, \beta \in (0, \infty)$

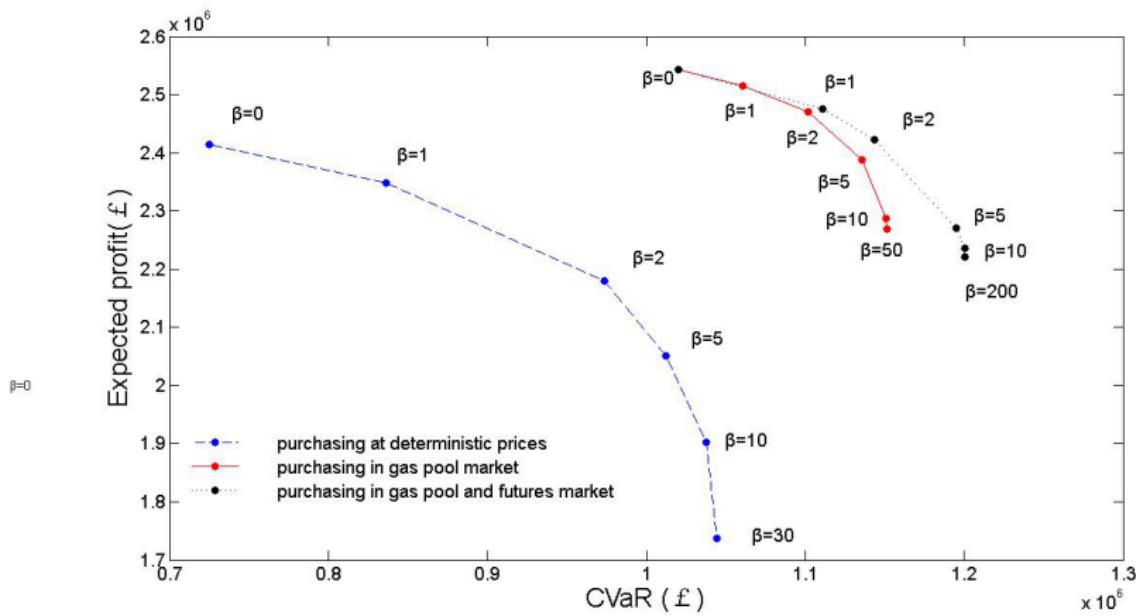
Peak periods	Off-peak periods
2-6,9-13,16-20,23-27,30,31	1,7,8,14,15,21,22,28,29

Futures Markets

Contract		Block 1	Block 2	Block 3
1	Block prices (£/MWh _e)	44.5	44	43.5
	Block volume (MW _e)	50	50	50
2	Block prices (£/MWh _e)	44.3	43.7	43
	Block volume (MW _e)	50	50	50

Contract		Block 1	Block 2	Block 3
1	Block prices (£/MWh)	18.3	18.5	19
	Block volume (MWh)	1500	1500	1500
2	Block prices (£/MWh)	18.4	18.6	19.5
	Block volume (MWh)	1500	1500	1500

Efficient Frontiers



Case 1 Hedging Strategy

β	Generation (GWh _e)	Futures contract sales (GWh _e)	Pool sales (GWh _e)	Fraction of futures contract sales
0	238.150	0.000	238.150	0.000
1	248.149	40.511	207.638	0.163
2	269.965	111.600	158.365	0.413
5	283.692	148.800	134.892	0.525
10	298.410	186.000	112.410	0.623
30	313.128	223.200	89.928	0.713

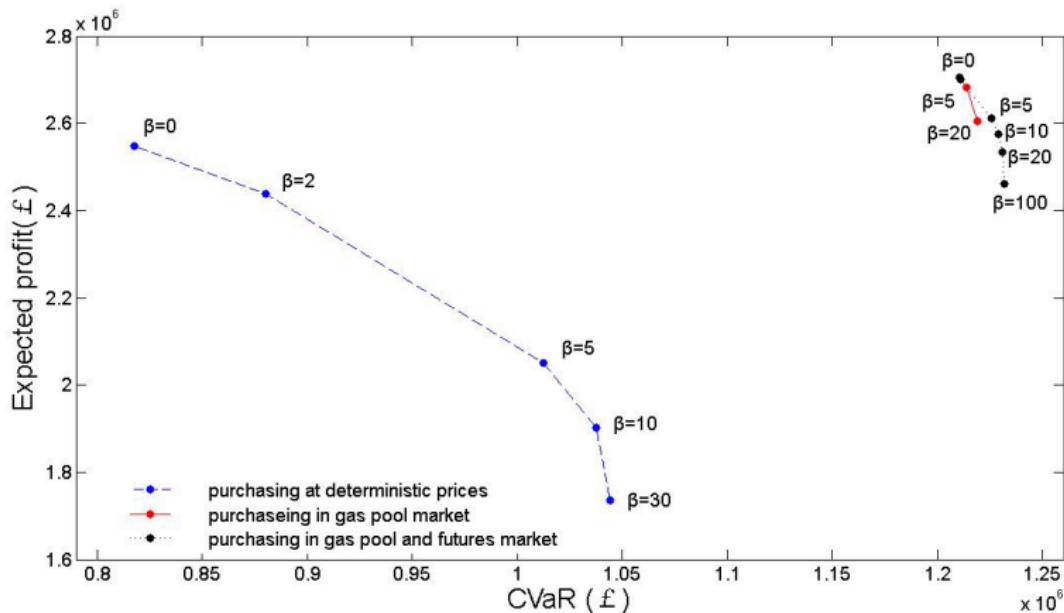
Case 2 Hedging Strategy

β	Generation (GWh _e)	Futures contract sales (GWh _e)	Pool sales (GWh _e)	Fraction of futures contract sales
0	244.388	0.000	244.388	0.000
1	248.230	16.405	231.825	0.066
2	254.258	40.511	213.747	0.159
5	264.327	74.400	189.927	0.281
10	275.380	111.600	163.780	0.403
50	277.202	117.732	159.470	0.429

Case 3 Hedging Strategy

β	Generation (GWh_e)	Electricity		Gas		Fraction of electricity futures sales	Fraction of gas futures purchases
		futures contract(GWh_e)	contract(GWh_e)	futures contract(GWh)	contract(GWh)		
0	244.388	0.000	0.000	0.000	0.000	0.000	0.000
1	253.430	37.200	47.129	0.147	0.084		
2	259.345	57.632	93.000	0.222	0.161		
5	275.380	111.600	139.500	0.405	0.228		
100	278.696	122.760	186.000	0.440	0.300		

Efficient Frontiers with Operational Flexibility



Case 1 Hedging Strategy with Operational Flexibility

β	Generation (GWh _e)	Futures contract sales (GWh _e)	Pool sales (GWh _e)	Fraction of futures contract sales
0	224.820	0.000	224.820	0.000
2	239.538	37.200	202.338	0.155
5	283.692	148.800	134.892	0.525
10	298.410	186.000	112.410	0.623
30	313.128	223.200	899.288	0.713

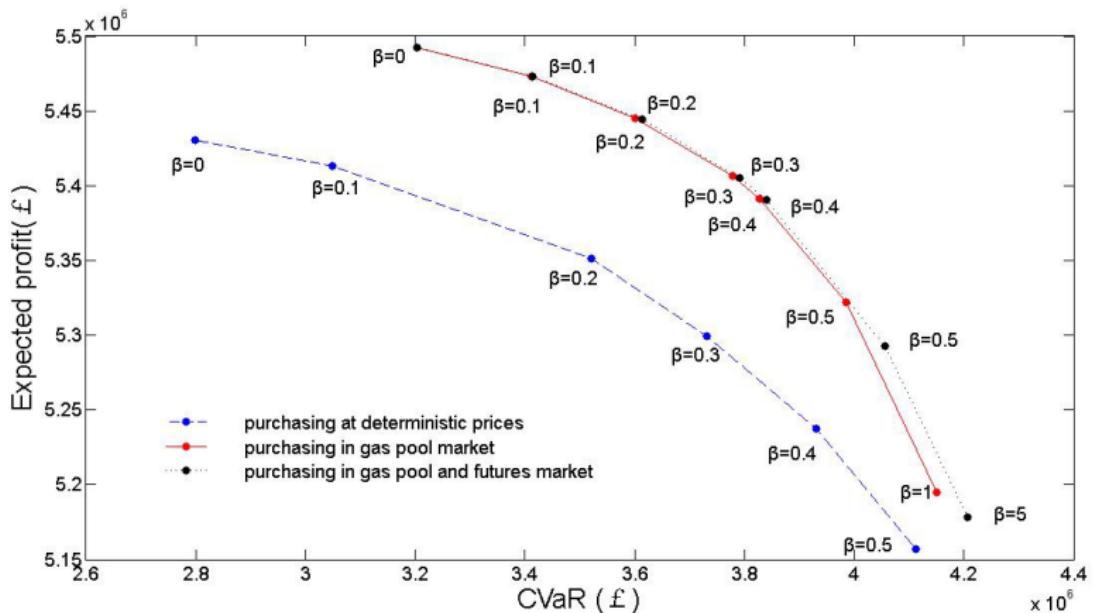
Case 2 Hedging Strategy with Operational Flexibility

β	Generation (GWh _e)	Futures contract sales (GWh _e)	Pool sales (GWh _e)	Fraction of futures contract sales
0	232.740	0.000	232.740	0.000
5	233.074	0.892	232.182	0.004
10	235.280	6.785	228.495	0.028
20	243.665	29.184	214.481	0.120

Case 3 Hedging Strategy with Operational Flexibility

β	Generation (GWh_e)	Electricity		Gas		Fraction of electricity futures	Fraction of gas futures purchases
		futures contract(GWh_e)	contract(GWh_e)	futures contract(GWh)	sales		
0	232.740	0.000	0.000	0.000	0.000	0.000	0.000
5	233.074	0.892	0.000	0.004	0.000	0.004	0.000
10	242.971	27329	46.500	0.112	0.086	0.112	0.086
20	246.666	37.200	68.843	0.151	0.126	0.151	0.126
50	250.661	47.872	93.000	0.191	0.167	0.191	0.167
100	258.103	67750.548	93.000	0.262	0.162	0.262	0.162

Efficient Frontiers with Higher Efficiency



Case 1 Hedging Strategy with Higher Efficiency

β	Generation (GWh _e)	Futures contract sales (GWh _e)	Pool sales (GWh _e)	Fraction of futures contract sales
0	345.603	0.000	0.000	0.000
0.1	346.721	37.200	309.521	0.107
0.2	349.439	111.600	237.839	0.319
0.3	352.164	148.800	203.364	0.423
0.4	355.470	186.000	169.470	0.523
0.5	358.776	223.200	135.576	0.622

Case 2 Hedging Strategy with Higher Efficiency

β	Generation (GWh _e)	Futures contract sales (GWh _e)	Pool sales (GWh _e)	Fraction of futures contract sales
0	343.059	0.000	343.059	0.000
0.1	344.412	37.200	307.212	0.110
0.2	346.129	74.400	271.729	0.215
0.3	347.878	111.600	236.278	0.321
0.4	348.403	122.760	225.643	0.352
0.5	352.271	163.623	188.648	0.464
1	357.912	223.200	134.712	0.623

Case 3 Hedging Strategy with Higher Efficiency

β	Generation (GWh _e)	Electricity		Gas		Fraction of electricity futures sales	Fraction of gas futures purchases
		futures contract(GWh _e)	contract(GWh _e)	futures contract(GWh)	contract(GWh)		
0	343.059	0.000	0.000	0.000	0.000	0.000	0.000
0.1	344.412	37.200	7.961	0.108	0.014		
0.2	346.129	74.400	46.500	0.215	0.081		
0.3	347.878	111.600	46.500	0.322	0.080		
0.4	348.403	122.760	46.500	0.352	0.080		
0.5	353.751	179.252	46.500	0.507	0.079		
1	357.912	223.200	139.500	0.624	0.234		
5	357.912	223.200	177.263	0.624	0.297		

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Conclusions

Summary

- SP may be a viable framework in which to make hedging and operational decisions in deregulated power sectors
- Incorporate correlated electricity and NG prices for a UK power producer's medium-term problem
 - Ignoring NG price uncertainty worsens risk/return profile
 - "Natural hedge" mitigates some risk but in an imperfect way
 - Possible to hedge more risk via NG futures
 - Greater operational flexibility decreases generation, makes the assumption of fixed NG prices worse, and reduces the gap between Cases 2 and 3
 - Higher efficiency increases generation, reduces the effect of the natural hedge, and increases the need for financial hedging
- Directions for future research
 - More realistic futures contracting curves
 - Unit failures and/or intermittent resources
 - Market power and/or competition